

# **Effects of Sound on the Marine Environment**

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## **LONG-TERM GOALS**

The long-term goals are to develop novel techniques to predict the effect of sound on the marine environment. This includes studying how marine life uses sound and how this use is impacted by human activity.

## **OBJECTIVES**

One objective of this research is to develop a framework for the Navy to predict how various sonar systems impact the marine environment. The ONR program, Effects of Sound on the Marine Environment (ESME) has produced numerous innovative tools from scientists in academia, government and industry. Under ESME, these were initially assembled in a high level prototyping software environment for evaluation by the scientific team. The initial prototyping was done using Matlab ([www.mathworks.com](http://www.mathworks.com)). The ESME team determined that some of these tools could have immediate value to the sonar and marine biology communities if they were available and were easy to use (e.g. through development of environmental impact statements). Starting in 2007, the ESME program has put together a team consisting Boston University (David Mountain), Biomimetica (Dorian Houser) and HLS Research to establish which ESME tools could be made available and to develop a simple user interface. The new ESME software suite will be open source and will not require Matlab.

## **APPROACH**

There are two user groups we envisioned for the ESME software suite. The first group involves those directly involved in preparing environmental assessments for the Navy. These assessments generally require multidisciplinary expertise, so one of the goals for the software suite is to reduce the need for specialized consultants and replace this with tools developed in the ESME program. The second user group is expected to come from the research community. Much of the research on ocean acoustics and marine mammals requires models to simulate the interactions between sound and marine life. Many of the experts are either in the sonar community or the marine biology community and we expect that a software package that brings these together will be welcomed by both groups. The strategy will be to develop the software so that both novice and more advanced users can take advantage of the developed

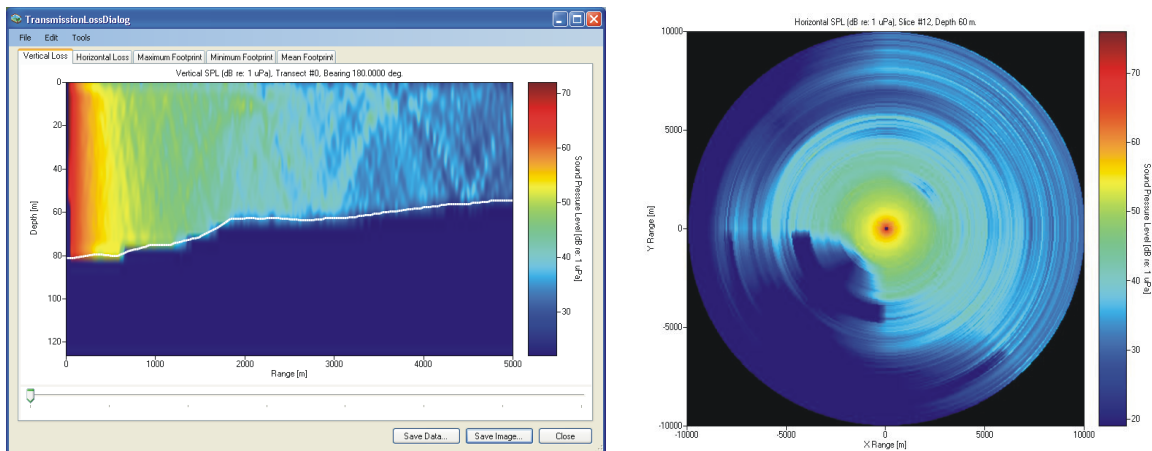
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capabilities in ESME. The approach is for HLS to provide the acoustic models the sonar signal processing tools as well as examples and tests. Biomimetica will assemble the Marine Mammal Movement and Behavior simulator (or 3MB). The BU group will primarily integrate the software and develop the user interface but is also providing ear modeling tools.

## WORK COMPLETED

### Integrating sound propagation models into ESME software package

There are four major acoustic propagation methods that are widely used: normal modes, ray/beam, parabolic equation, and spectral integration. These four model-groups allow different marine environments to be handled efficiently. For instance, parabolic equation models are often a good choice in range-dependent environments while ray/beam models are often the best choice for high frequency and/or broadband calculations. These models had previously been integrated into the Matlab ESME prototype software for initial testing. The ray/beam method proved to be the most versatile and was therefore chosen to be the first model included in the new ESME software suite.



**Figure 1: Example screen shot from the ESME software suite. Left panel shows the transmission loss along a range-depth slice and the right panel is the Nx2D horizontal view.**

The ray/beam approach balances the need for acoustic fidelity with the need for reasonable computation time, user simplicity and applicability to a wide range of environments and sonar types. In addition to the ray/beam model, several other acoustic models will be integrated into the software (for specialized applications) and HLS is working closely with the BU and Biomimetica teams on this effort.

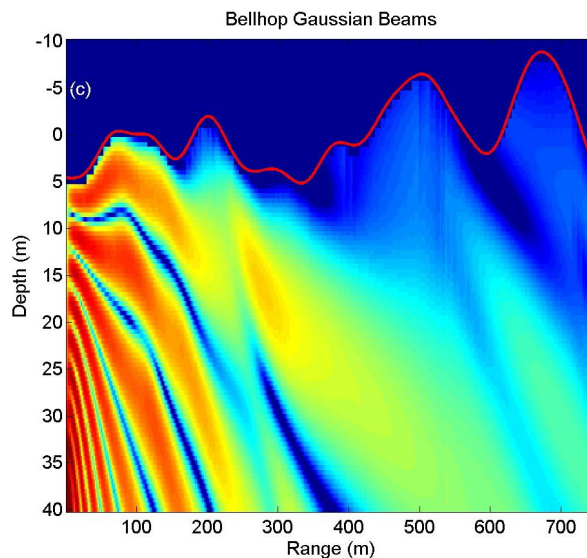
### Integrating environmental databases

Much of the effort in propagation modeling is typically spent on finding the correct environmental input data (such as oceanography, bathymetry and sediment properties). This year, we have begun to evaluate unclassified databases for inclusion in the software suite. For the oceanography, (e.g. sound speed in the water column) there are historical databases (climatologies) that are a function of season or month. There are also Navy products to forecast the oceanography for more accuracy but these may not generally be available. There is also a required input for the seabed which includes the bathymetry and the seafloor reflection loss. Unclassified, detailed bathymetry maps are generally available and can

be accessed through the Naval Oceanographic Office. However the seafloor reflection loss is more difficult to characterize and we have therefore begun evaluating approaches as to how include the sediment properties. The initial approach we are taking is to include the Bottom Sediment Type from OAML (Oceanographic and Atmospheric Master Library). The unclassified sediment type database can be linked to sediment geacoustic properties through grain size.

### Surface scattering and surface ducts

Near the surface of the ocean winds tends to stir-up the water causing an isothermal layer sometimes referred to as the mixed layer. Combining these isothermal conditions with depth increasing hydrostatic pressure leads to a slightly upward-refracting sound speed profile, or surface duct. This duct traps acoustic energy so that all propagation paths interact with the surface. The low surface losses lead to long-range, low-loss acoustic propagation. This is of particular concern for many sonar systems that operate in the surface duct such as those that are mounted to the hull of a ship. When marine mammals are also in the surface duct this can lead to potentially disastrous conditions. When modeling for risk assessment the application of zero surface losses (as results from a flat surface) lead to perfect reflections, so the down-range propagation losses may be greatly *underestimated*. However, using standard wind-driven surface reflection loss formulas the losses may be greatly *overestimated* for many types of sonar systems. The surface reflection loss approach to estimating the down range losses needs to be applied cautiously since the signal integration time can play a critical role. For short-duration signals the sea surface may appear rough but frozen (static) and therefore multipaths will arrive with amplitudes that can be similar to the flat surface. This is in contrast to signals with long integration times (e.g. continuous) where the surface is dynamic and multipath will tend to cancel when integrated over time. Many of the acoustic models assume single-frequency continuous propagation. This year we have begun integrating a surface scatter tool into the ESME time-series simulator. This is based on the Bellhop Gaussian Beam code already integrated in the software suite. This will allow a time-varying sea-surface to be simulated to estimate the losses [1]. In Fig. 2 is an example showing the sound field interacting with a rough sea-surface (e.g., from swell).

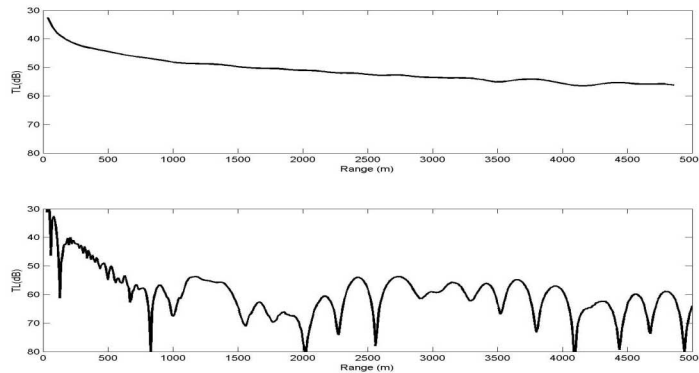


**Figure 2: Pressure intensity of a rough sea-surface simulation using Bellhop Gaussian Beams. Source is at 40 m depth. Red line shows the sea-surface boundary.**

### Implementing short-cuts and resolution criteria for optimizing efficiency

Most propagation models have approximations built in and these are often designed for application to general ocean acoustic problems. Often, there is a point in which the model accuracy is beyond the requirements for the problem. For example, it probably doesn't make sense to worry about modeling with extremely high fidelity when there is a large uncertainty due to the environmental inputs. By matching the model fidelity to the problem there is potential for a large payoff in computation speed. There are examples where the most accurate model could take several days to compute while with some reasonable approximations this could be done in minutes. The end results may be exactly the same in terms of accumulated energy or number of takes estimated. The more efficient algorithms will allow the user to explore many scenarios without being frustrated by long run times.

This year we have begun to evaluate *options* for faster, lower fidelity (possibly lower resolution too) computations. These lower fidelity calculations can, of course, be followed up with more accurate model runs for comparisons. We are evaluating ASTRAL which is one of the Navy standard models in OAML. While ASTRAL does not compute much of the structure of a coherent transmission loss curve it is extremely fast. Further, for certain types of applications this type of lower fidelity calculation may be sufficient. In many cases, the coherent TL curves are processed to make them smooth by range or frequency averaging so ASTRAL may achieve a similar result with less computation. Figure 3 shows an example of ASTRAL and a coherent TL calculation to illustrate the differences.



**Figure 3:** Example of simulation using ASTRAL (top) and coherent TL model (below). Much of the coherent structure of the field is removed using ASTRAL but the computation time is very fast.

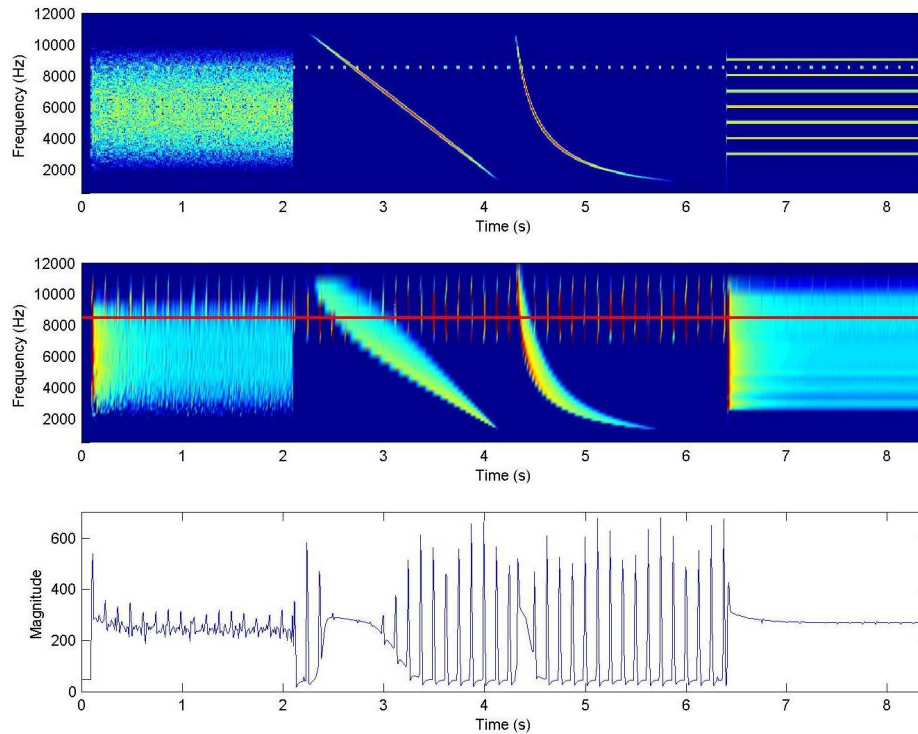
### Testing

A key part of the development of the ESME software suite is providing examples and test files for illustrating usage and for validating the results. We are currently developing a set of test problems that will exercise various modules and be compared against known solutions. The exact number and types of tests will continue to be developed as the user community is defined.

### RESULTS

The tools from the ESME software suite were used to illustrate how different sonar signals might mask natural sounds used by marine life [2]. We used models to examine options for active sonar signals with

the goal of determining marine mammal risk factors. The intent is to examine possibilities for reducing risk to marine mammals while maintaining sonar system performance. Obviously, lower source power could reduce risk factors but it would probably defeat the purpose of the sonar system. Here, we consider spread spectrum (or pseudo-random noise) waveforms as a possibly more benign signals for marine mammal exposure. Although such waveforms have been used extensively in many fields and have been suggested for sonar systems, in this study the effort was towards understanding the potential effects on both the marine mammals and the implications for sonar processing. The signals were played through the Boston University Earlab which produces a simulated cochleagram. This allows the phenomenon of masking to be observed through the ear model. The difficulty is obtaining the appropriate model parameters for the ears of marine mammals and this is an active area of research. Here, we used a slightly modified human ear model to illustrate how the tools will work.



**Figure 4:** To show an example of ear modeling, we created an echolocation-like signal and added it to the sonar signal transmission (clicks @ 8.5 kHz). The top panel shows the spectrogram of the click train with the set of sonar signals. The middle panel is the model output cochleagram. The lower panel is a slice taken at 8.5 kHz to better see the click levels in comparison with the sonar signals. In the lower panel the clicks are just visible during the PRN sequence. There are short periods where the clicks are not visible during the LFM and HFM transmissions and during the multi-tones there is no sign of the clicks.

## **IMPACT/APPLICATIONS**

This work is bringing together state-of-the-art acoustic modeling and marine mammal behavior modeling into a simple, intuitive software package. We envision this software will be highly useful for preparing environmental assessments to estimate risk to marine life. We also envision the research community will have interest in the developed software to aid in understanding how sound is used both by humans and by marine life.

## **TRANSITIONS**

None at this time.

## **RELATED PROJECTS**

The ESME research on acoustic modeling is being done in close collaboration with ONR Ocean Acoustics projects by Martin Siderius and Michael Porter.

## **REFERENCES**

[1] Martin Siderius and Michael Porter “Modeling broadband ocean acoustic transmissions with time-varying sea-surfaces”, J. Acoust. Soc. Am. (submitted).

## **PUBLICATIONS**

[2] Martin Siderius, Michael Porter and David Mountain “Modeling alternative sonar waveforms to determine risk factors for marine mammals”, The Effects of Noise on Aquatic Life, Nyborg, Denmark, August, 2007.